



# 3-Dimensional surrogate cloud fields with measured structures

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# BBC campaigns

- Keywords: boundary layer water clouds, structure & radiation, climate
- Airplanes
- Tethered balloons
- Satellites
- Regional network with lidar, ir-radiometers
- Ground based remote sensing





# BBC campaigns

- BBC1: August, September 2001
- BBC2: May 2003
- Chaotic skies, typically Dutch cloudscares

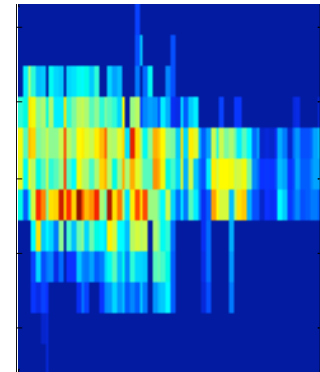






# BBC campaigns

- BBC1: August, September 2001
- BBC2: May 2003
- Chaotic skies, typically Dutch cloudscares
  - High quality measurements for testing
- Open database
  - <ftp://bbc.knmi.nl>
- Beautiful measurements, but modellers need 3D fields
- Dimensionally challenged





# Motivation

- Can not measure a full 3D cloud field
- Can measure many (statistical) cloud properties
- Generate cloud field based on measurements
- Emphasis on good structure for radiative transfer

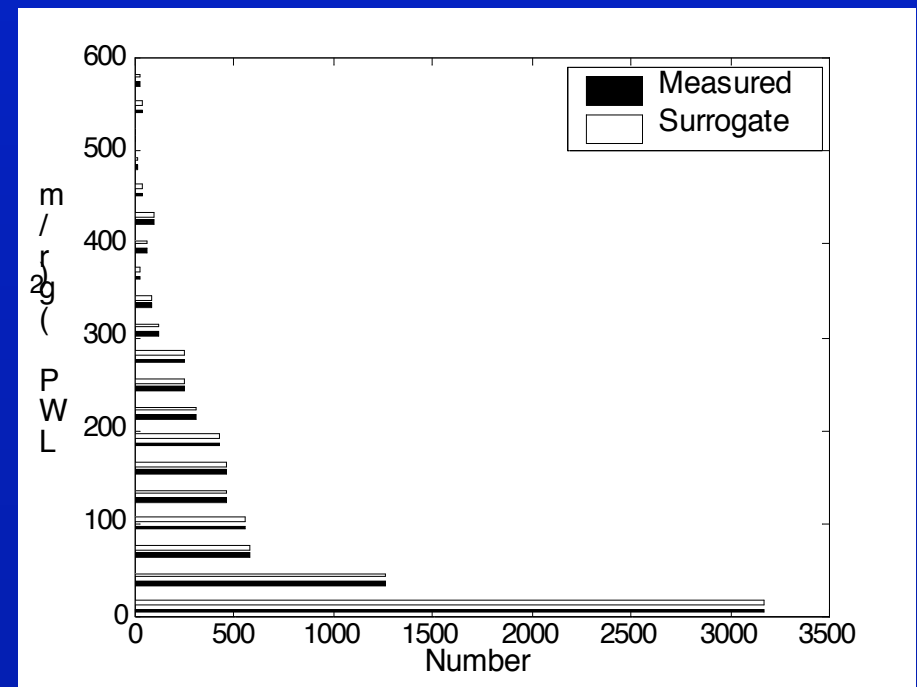




# Structure & radiation

## ■ Distribution

- Amplitude (LWP, LWC,  $\tau$ ) alone is already good
- Success of Independent Pixel Approximation (IPA) at large scales





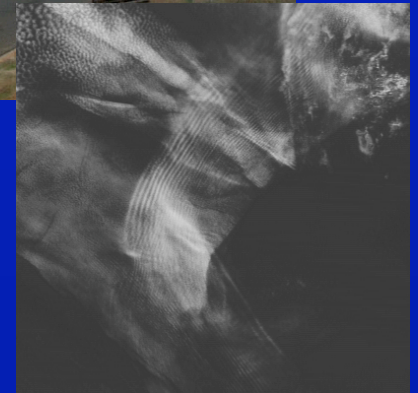
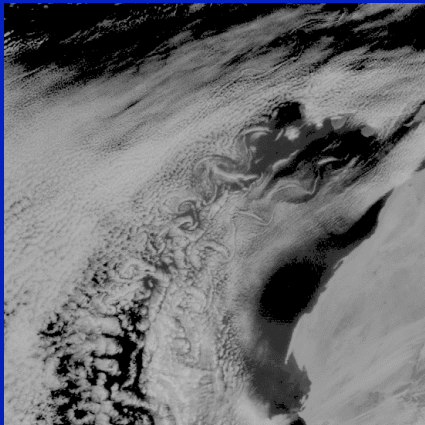
# Structure & radiation

- Power spectrum
  - Spatial linear correlations
- Full spectrum



# Measured power spectrum

- Scale breaks
- Waves
- Land sea mask
- ...



Satellite pictures: Eumetsat





# Validation surrogate clouds

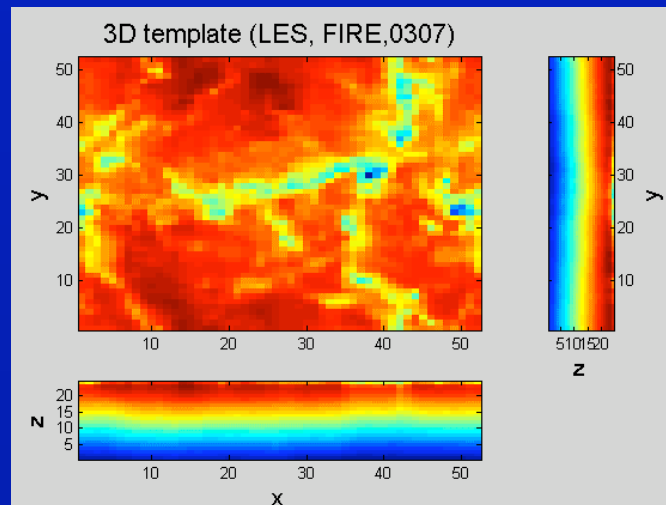
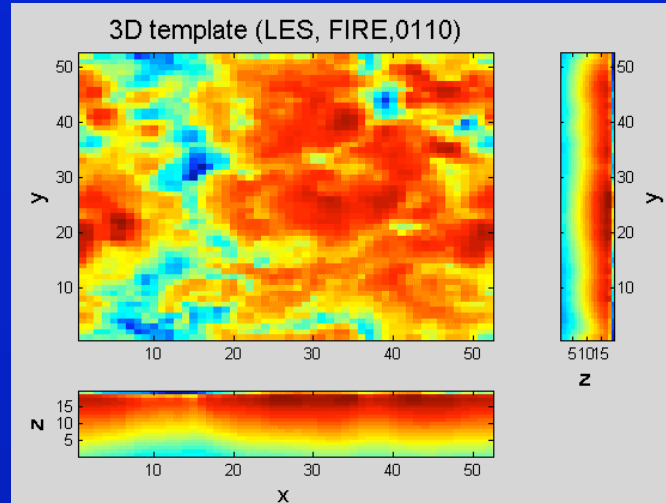
- Is this statistical description good enough?
- 3D LWC fields from LES modelling
- Make surrogates from their statistics
- Calculate radiative properties
  - Radiances  
(remote sensing; Steffen Meyer)
  - Irradiances  
(radiative budget; *Sebastián Gimeno García*)
  - Actinic fluxes  
(chemistry; Anke Kniffka)
- Compare them



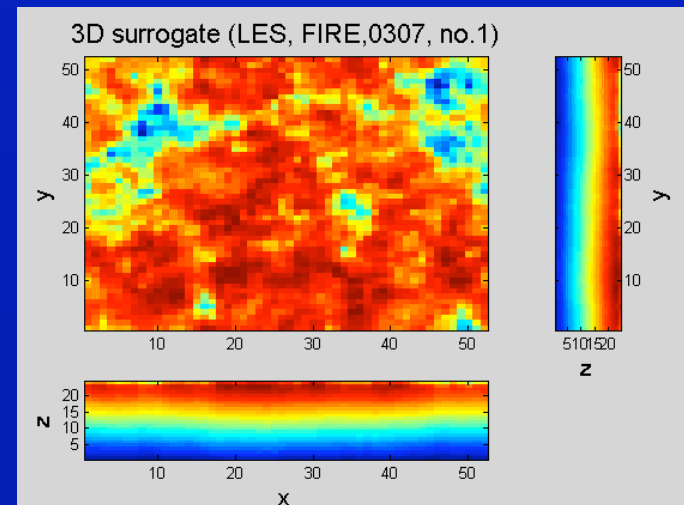
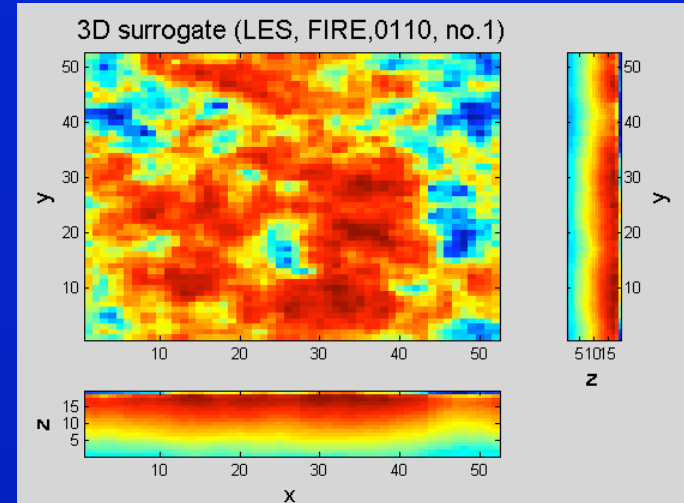


# LES Surrogates - LWC

## LES originals



## Surrogates





# Validation results

- Irradiances
  - RMSE mean:  $< 0.03 \%$  of the radiative budget
  - Monte Carlo error, statistically not significant
- Radiances
  - RMSE mean:  $< 0.3 \%$
  - Monte Carlo error, statistically not significant
- Actinic flux
  - RMSE mean:  $< 1.4 \%$
  - No error estimate (SHDOM)





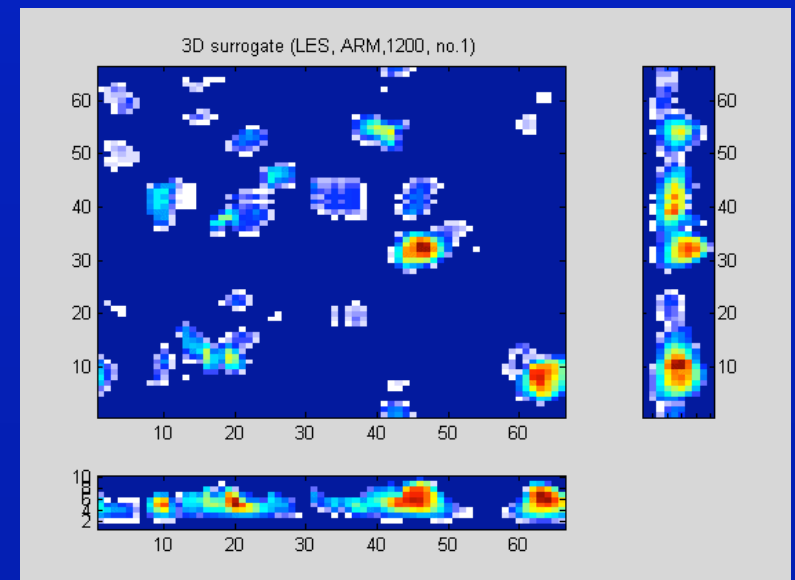
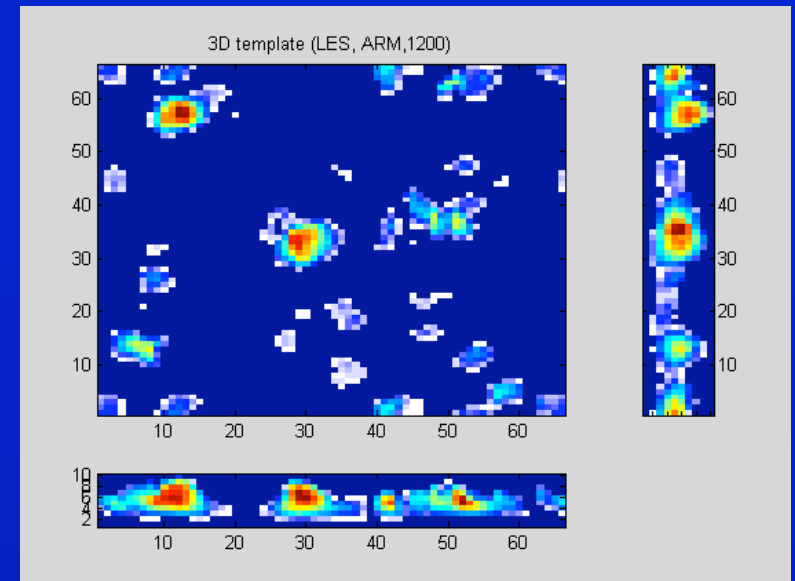
# Validation results

- Fields with only one statistic (i.e. PDF or Fourier)
  - clearly worse
  - statistically significant
- ⇒ The statistical description is probably good enough
  - LES stratocumulus and within 1 %
  - Limitation is likely the amount of data



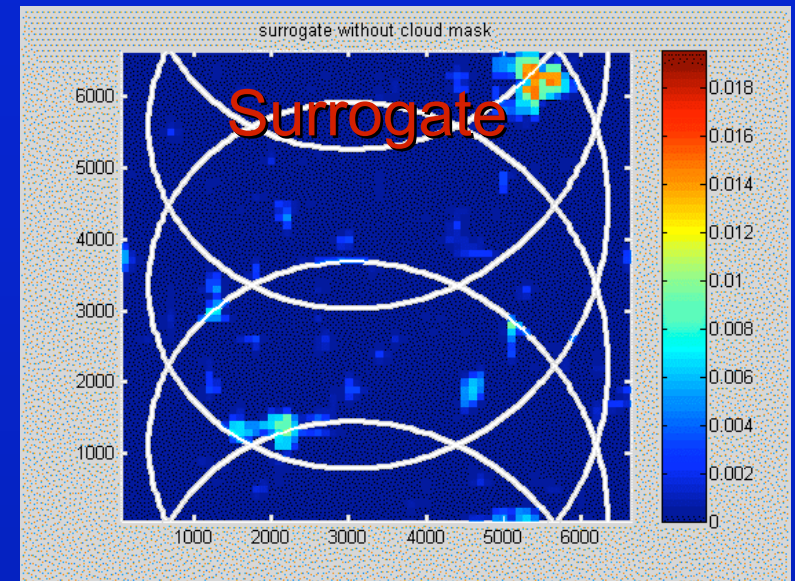
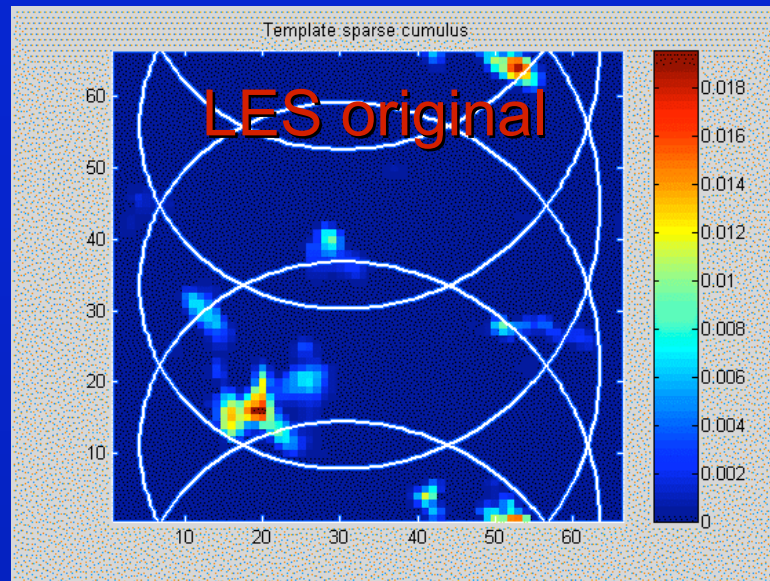
# Validation cumulus

- Developed a more accurate Stochastic IAAFT algorithm
- Surrogates are copies of templates
- In practise the bias is likely still there as you cannot measure the power spectrum that accurately





# Validation cumulus

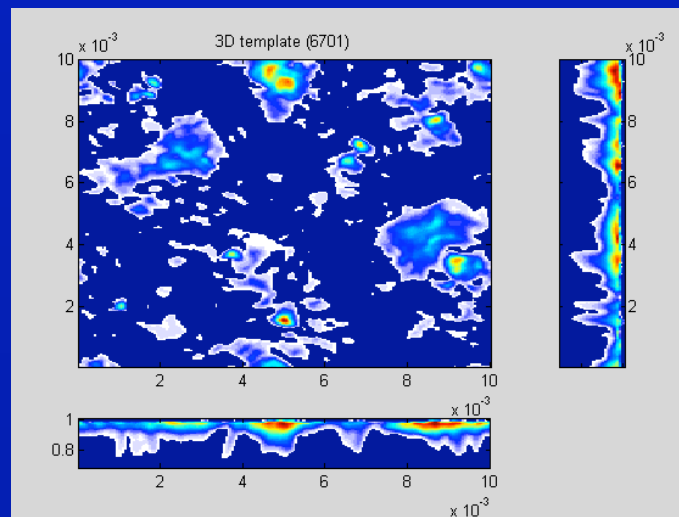
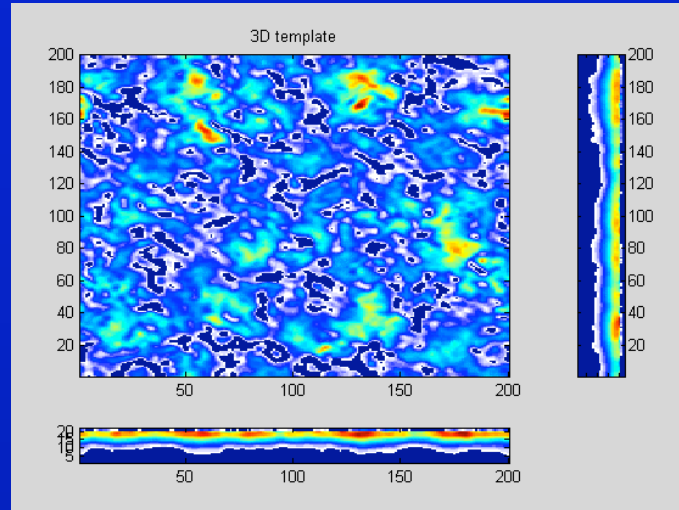




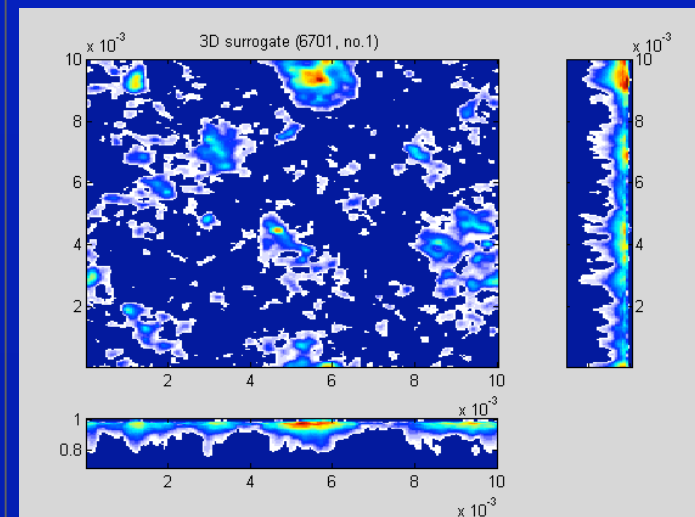
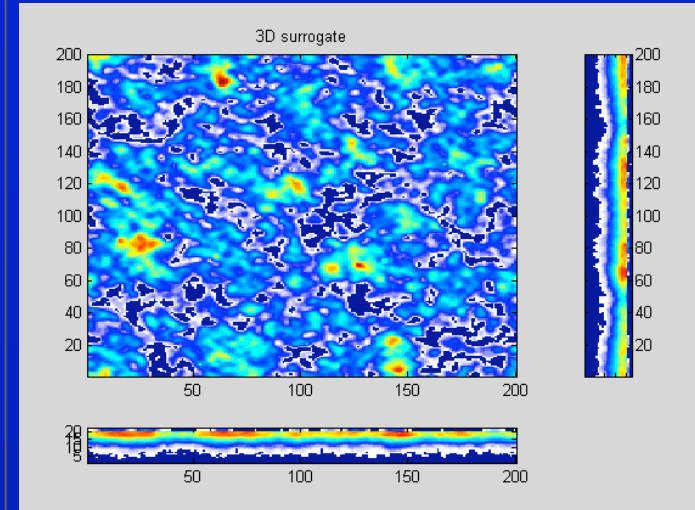


# Validation broken clouds

## LES originals



## Surrogates

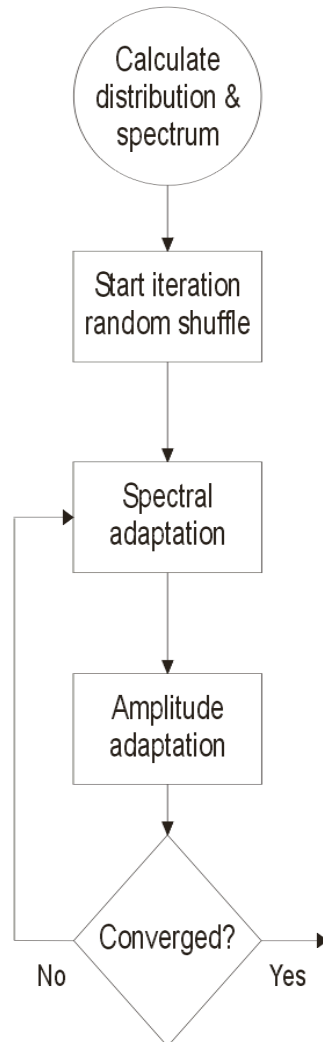




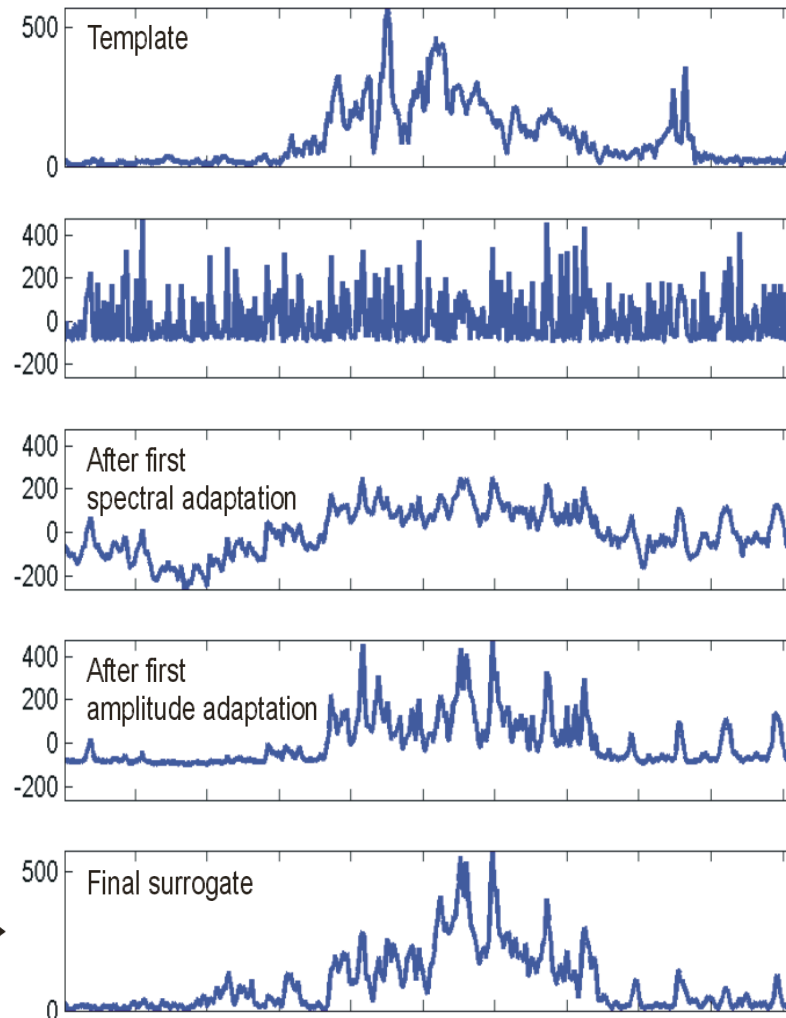


# Iterative algorithm (Schreiber and Schmitz, 1996)

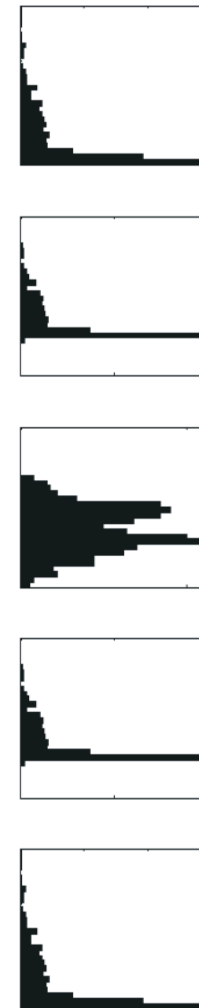
## Flow diagram



## Time series



## Distribution





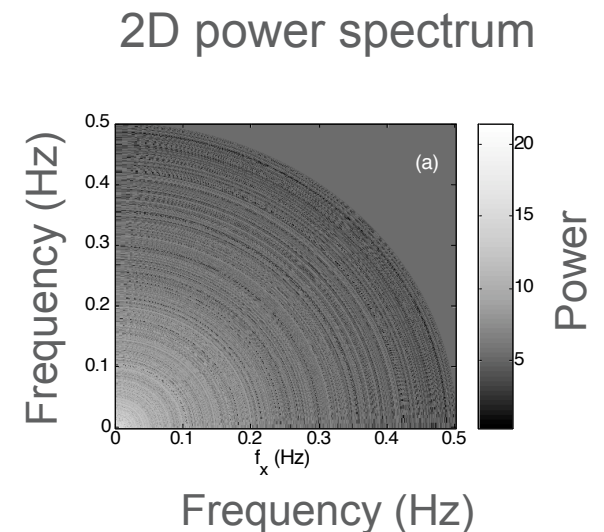
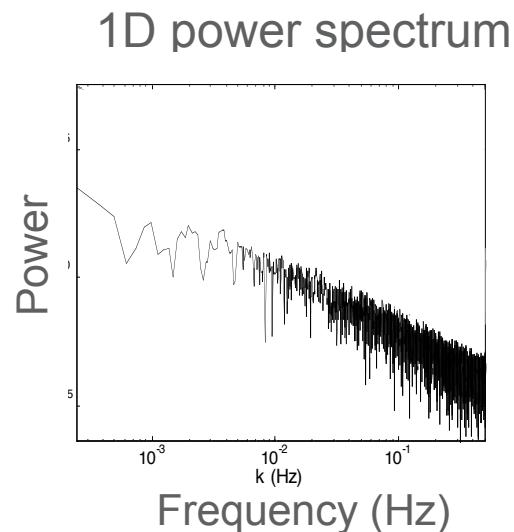
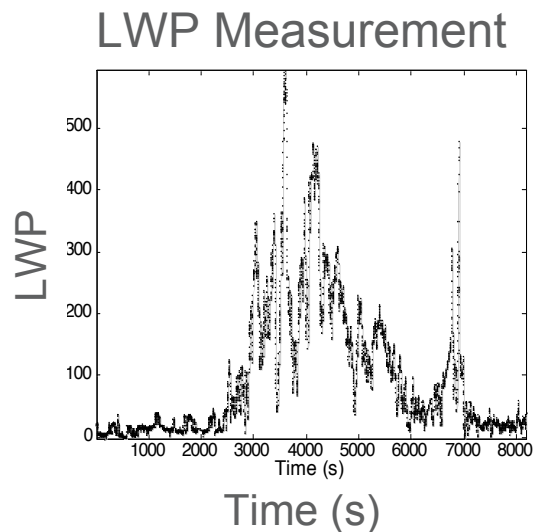
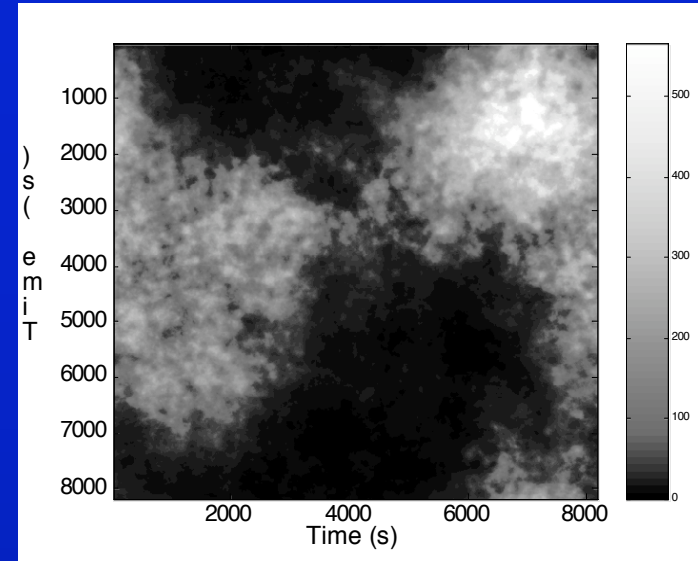
# Iterative algorithm

- Original problem
  - Generate a cloud similar to measurements
- New problem
  - Based on limited data estimate:
    - distribution
    - power spectrum



# Estimate spectrum – method 1

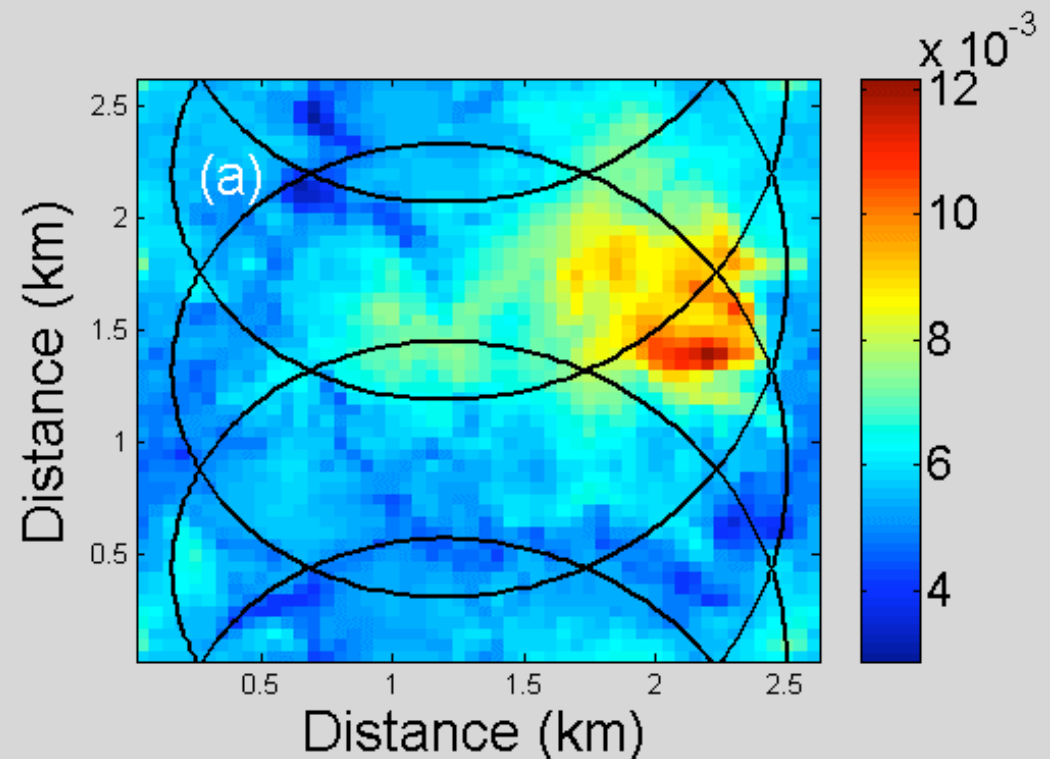
- Add a dimension
- Assume isotropy
- Rotate and scale power spectrum





## Estimate spectrum – method 2

- Scanning measurement
- Estimate 2D-autocorrelation function
- 2D anisotropic power spectrum

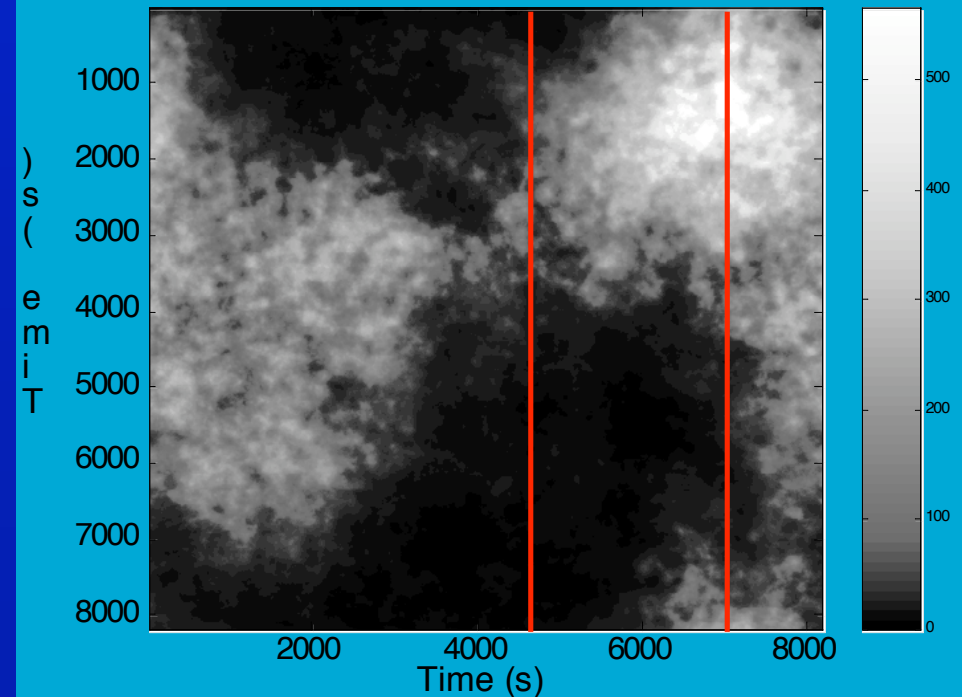






# Estimate distribution - zenith

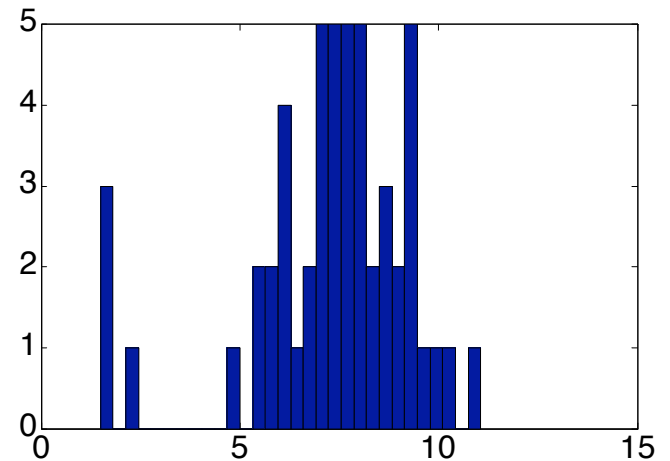
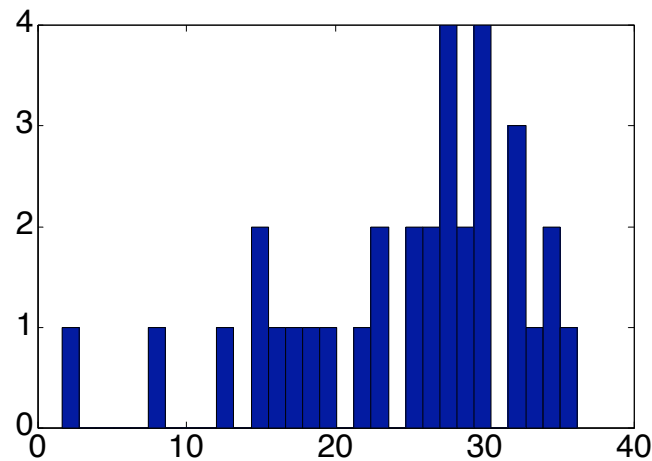
- Option: PDF field is measured PDF
- However!
  - Inhomogeneous (non-stationary) field
  - Underestimate the width distribution





# Estimate distribution - zenith

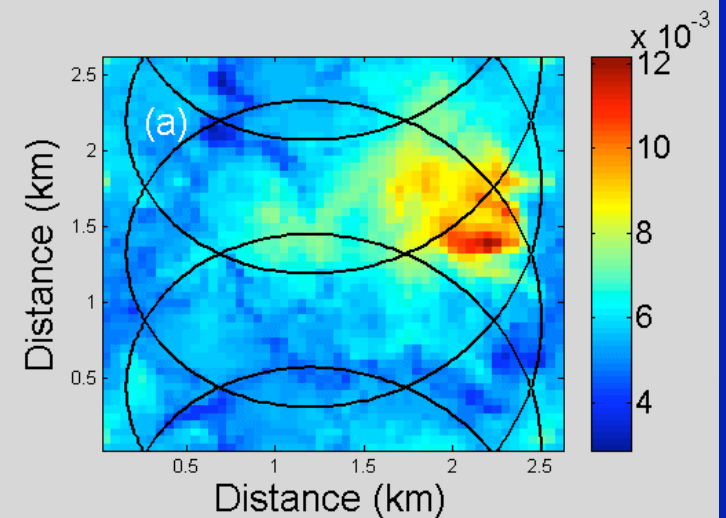
- Relative reduction in variance
- Zenith measurement
- Simulated on LES clouds





# Estimate distribution - scan

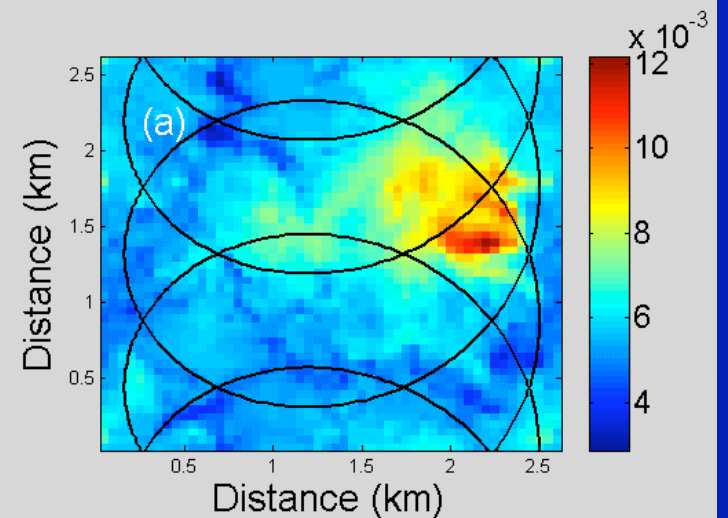
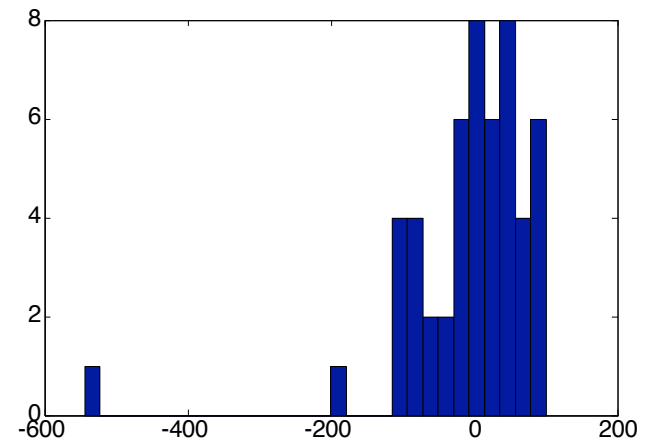
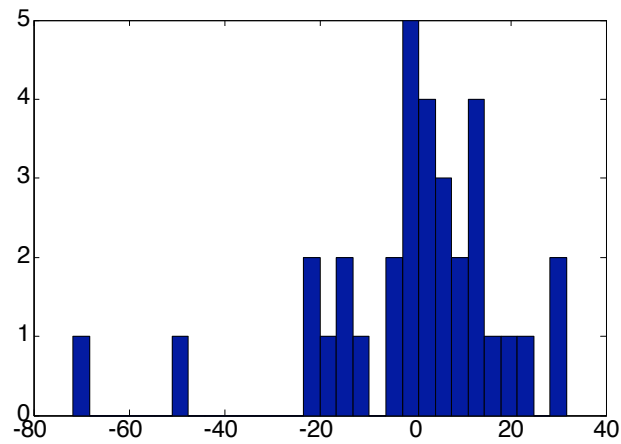
- Correcting
  - Frank Evans
- More data
- Spread
- ⇒ Scanning







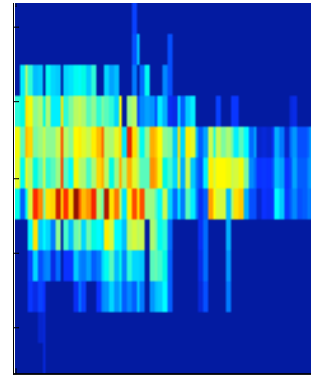
# Estimate distribution - scan





# Estimate distribution - height

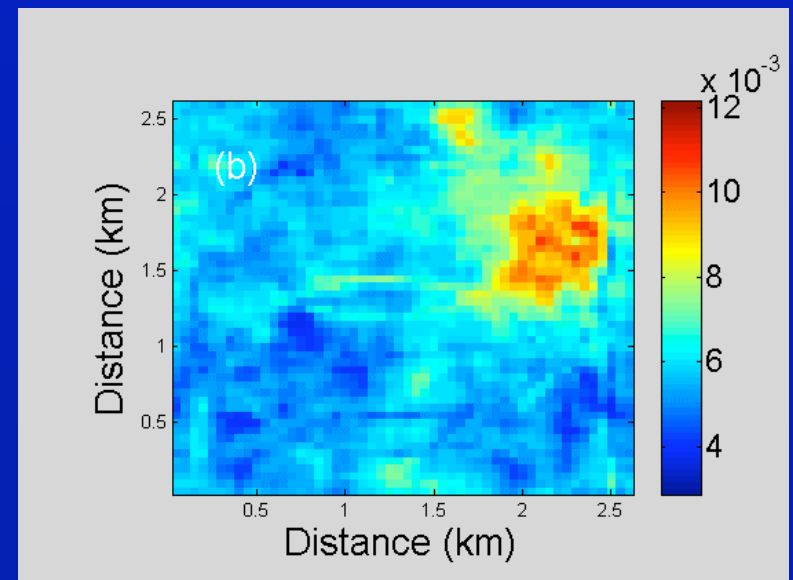
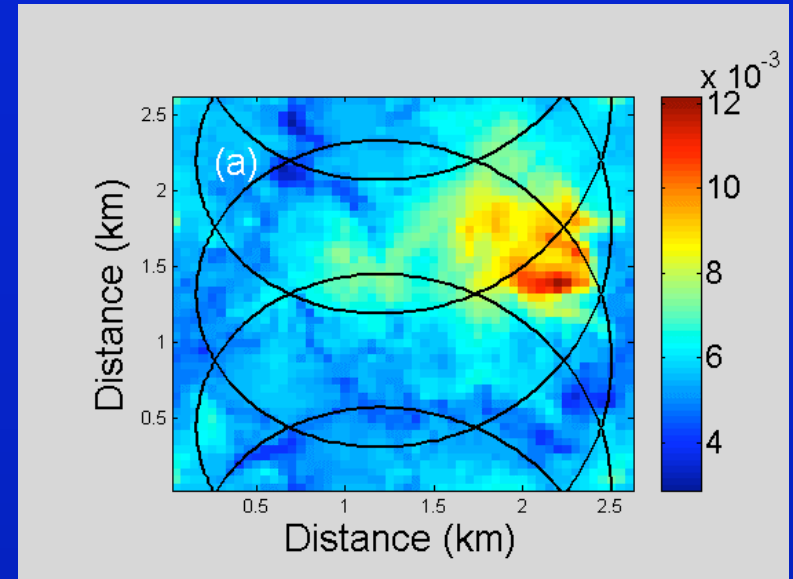
- Distribution as a function of height





# Added: Local values

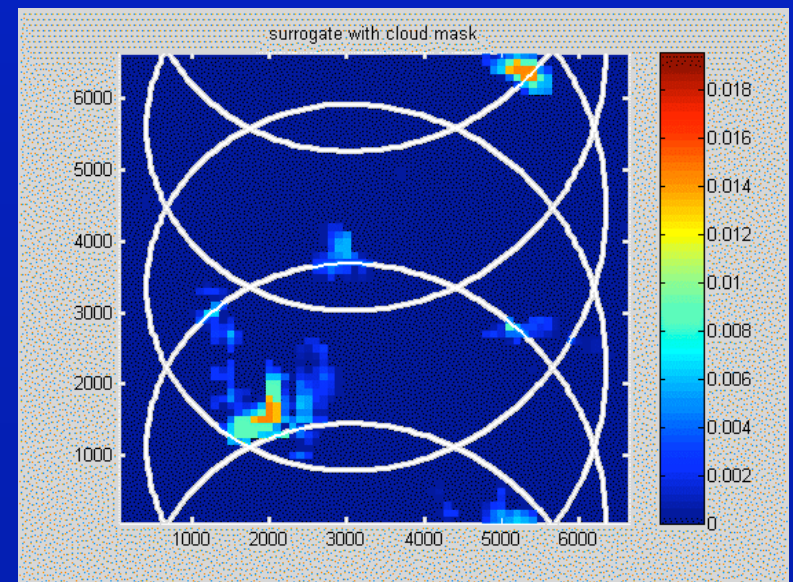
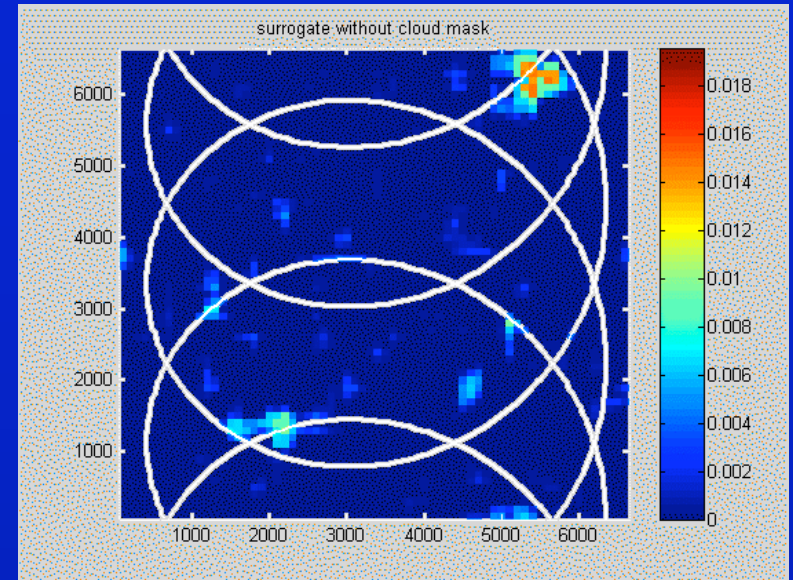
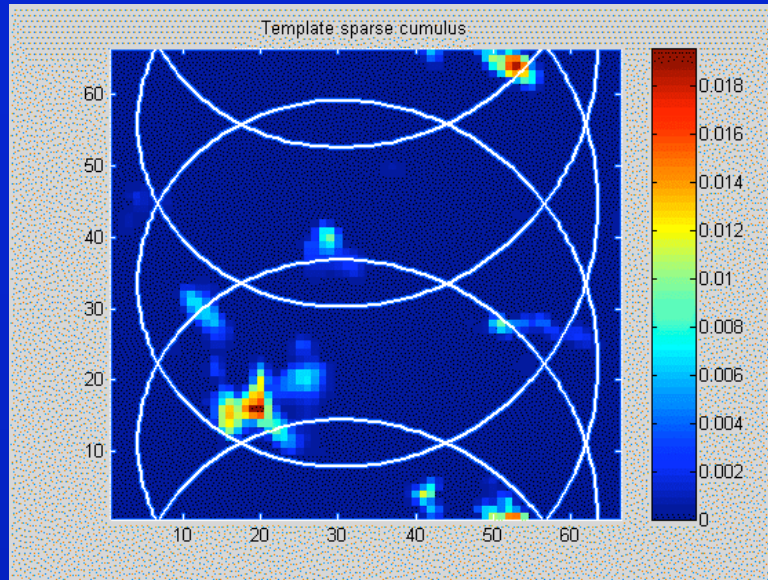
- Input from scanning measurement
  - Amplitude distribution
  - 2D power spectrum
  - The measured values on the spiral







# Added: Local constraint & mask

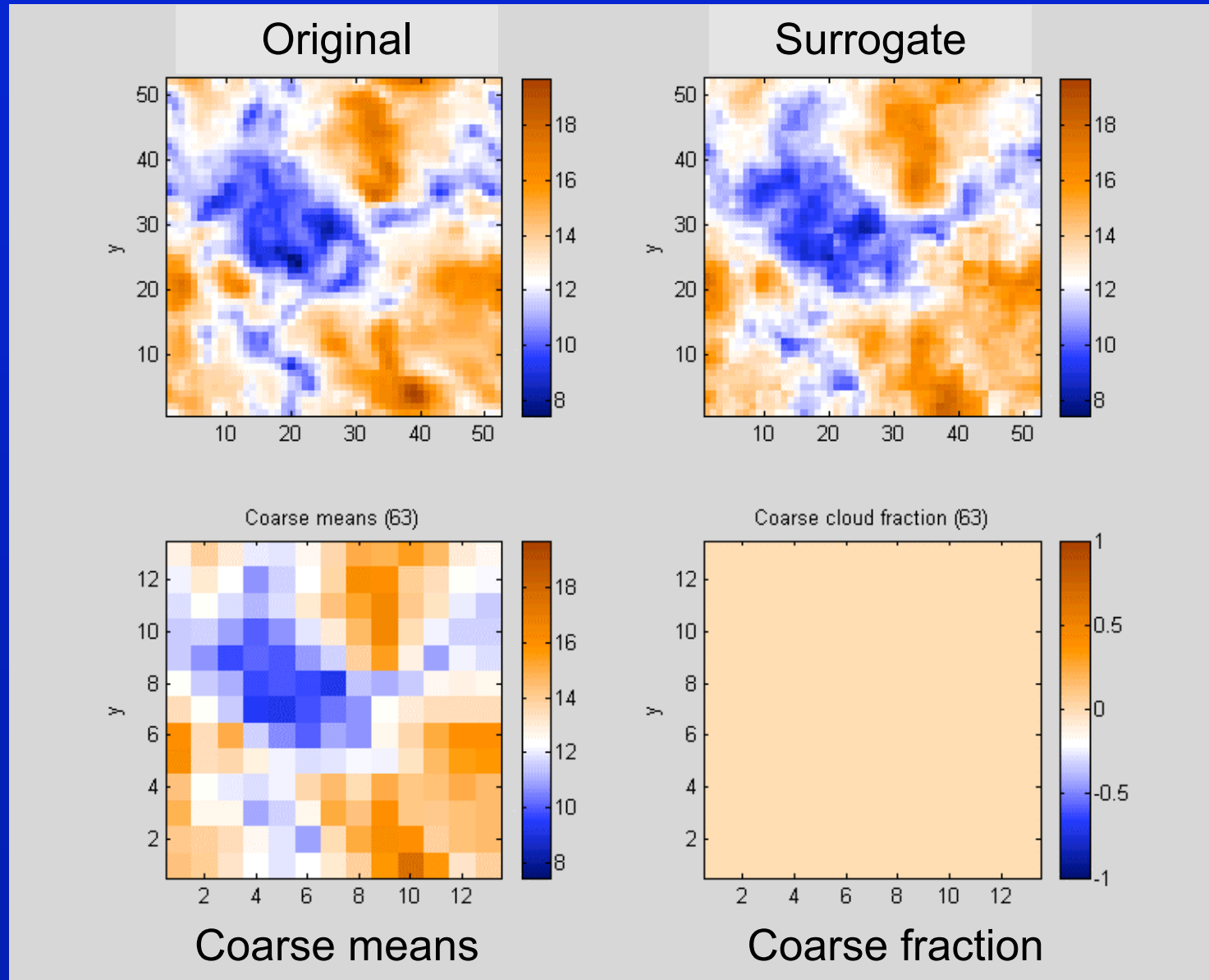


Surrogate with  
cloud mask



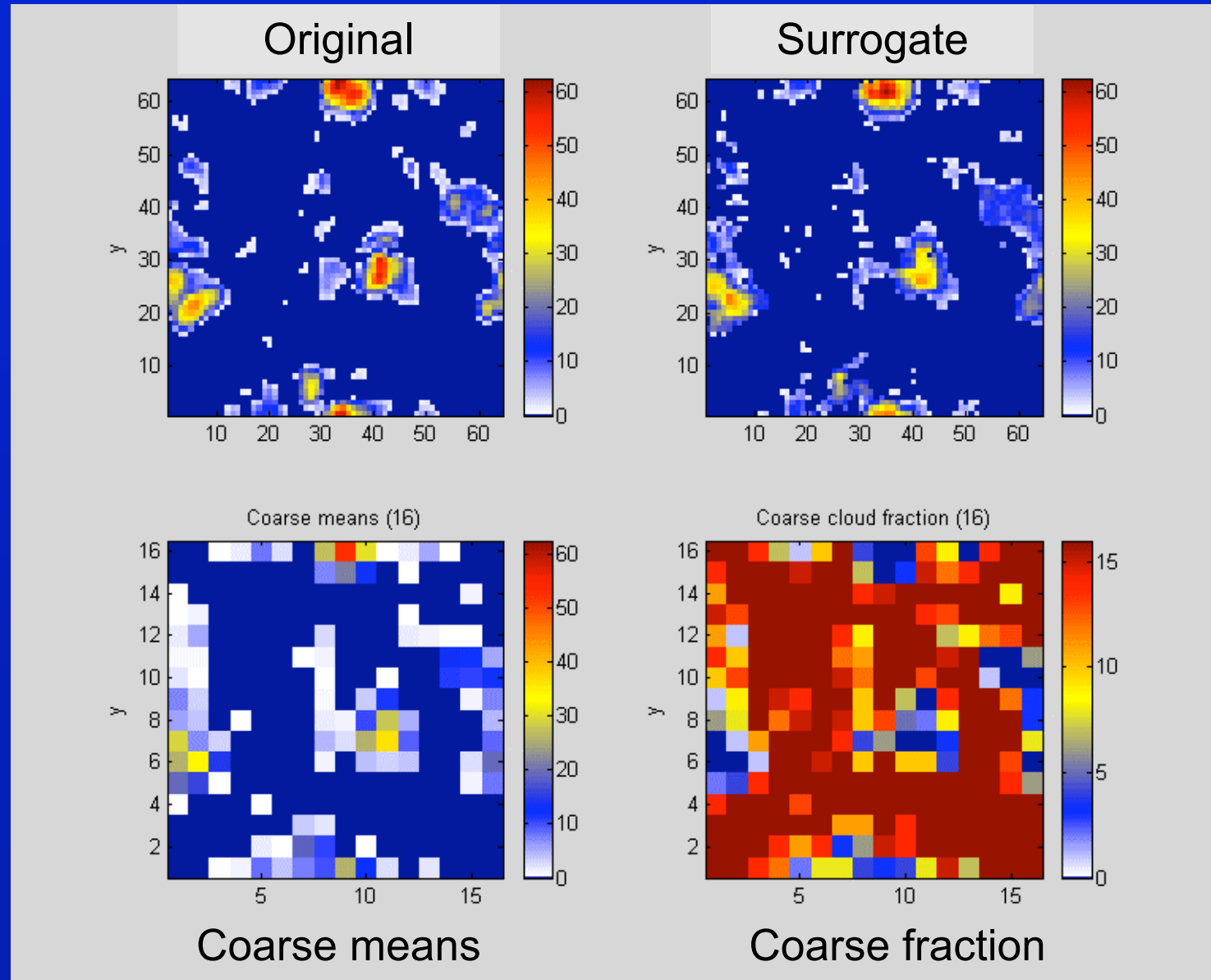


# Added: Coarse means





# Added: Coarse means & mask





# Applications

- Closure studies
  - Bring micro-physics and radiation together
  - Poster: 3D surrogates from in situ measurements (Sebastian Schmidt, Ronald Scheirer, Francesca Di Giuseppe)
- Structure studies
- Fractal generator
- Geophysics



# Applications

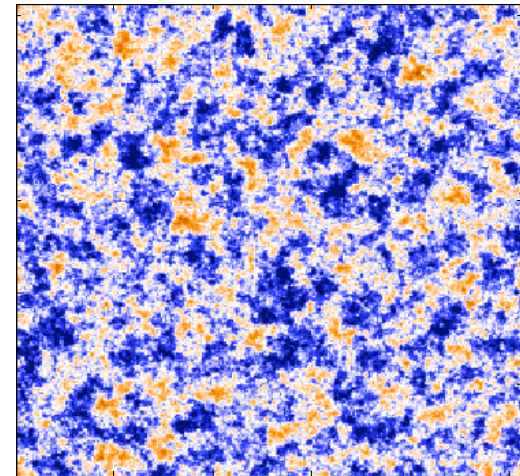
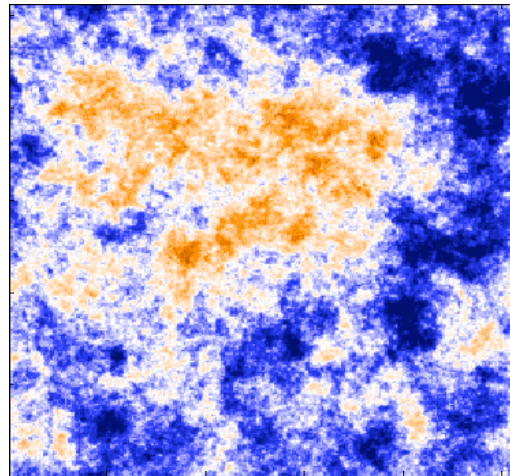
- Closure studies
- Structure studies
  - How good is the fractal approximation?
  - How accurate do you need to know the PDF?
- Fractal generator
- Geophysics





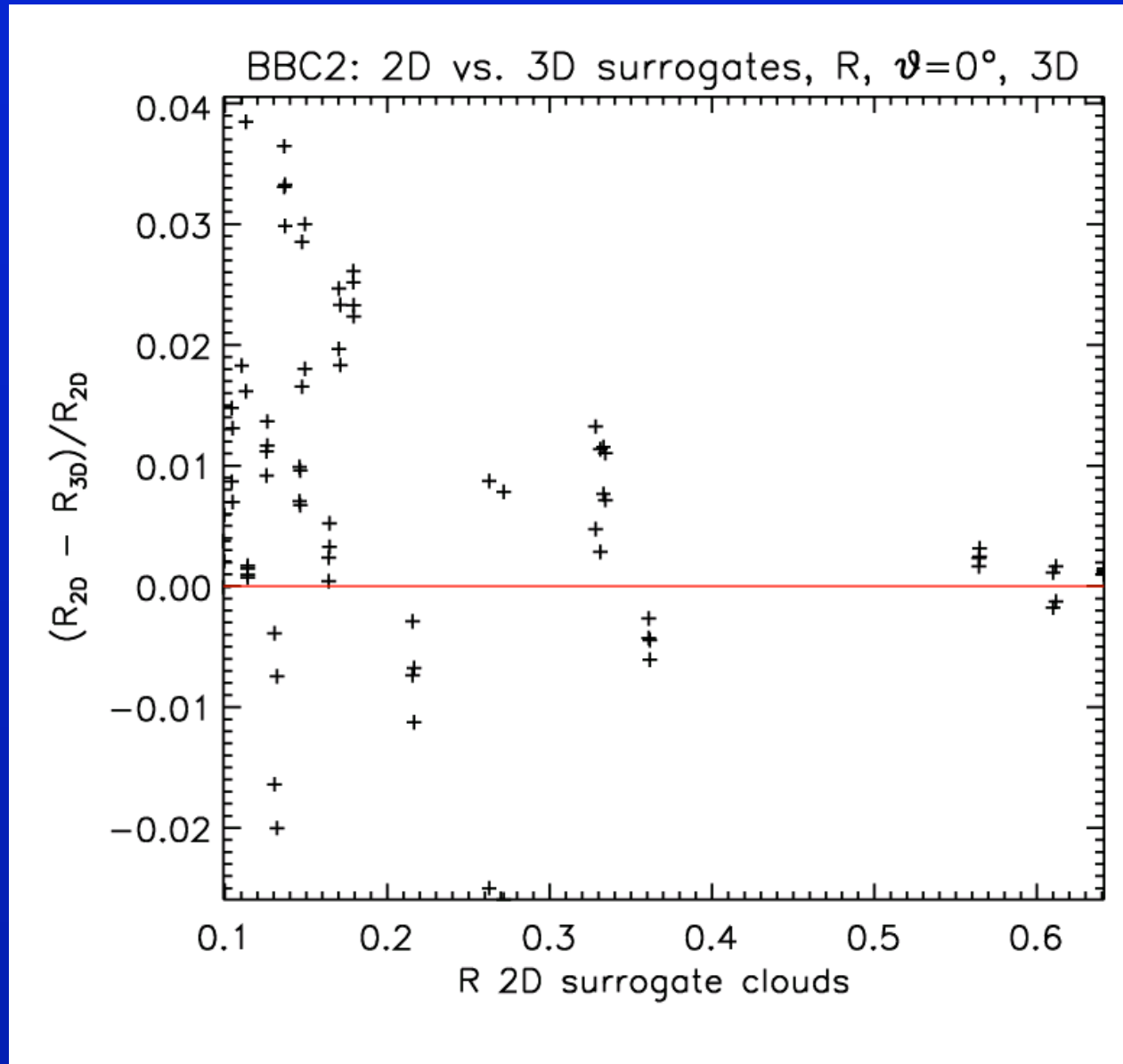
# Structure studies

- 2D tdMAP clouds
- IAAFT surrogates
  - Full structure
  - Only correlations at small scales
- Compare radiative properties





# 2D & 3D reflectance





# Applications

- Closure studies
- Structure studies
- Fractal generator
  - Sensitivity studies
    - Retrievals and parameterisations
  - Spectrum and PDF varied independently
  - Broad-band radiometer EarthCARE
    - Jaime F. Gimeno (University of Valencia) & Howard Barker
- Geophysics



# Applications

- Closure studies
- Structure studies
- Fractal generator
  
- Soil temperature fields LES
- Rain fields
  - Downscaling low resolution atmospheric models to high resolution hydrological models
- Surrogate run-off
- Wind stress fields
- Soil properties
- ...





# Comparison cloud generators

3,2: 3D, 2D; S: Structure; P: PDF;  
L: Local values; M: Mask

- 3SPLM ■ IAAFT method
- 3SP\_\_ ■ Cumulus fields (Evans; structure of a binary mask)
  
- 3SPL\_ ■ CLABAUTAIR (Scheirer and Schmidt)
- 2\_\_L\_ ■ Shift cloud (Schmidt; Los and Duynkerke)
- 2\_\_L\_ ■ 2D-2D Ice cloud (Liou et al.)
  
- 2SP\_\_ ■ tdMAP (A. Benassi, F. Szczap, et al.)
- 2SP\_\_ ■ Multi-fractal clouds
- 2S\_\_\_ ■ Bounded Cascade and other fractal clouds
- 2S\_\_\_ ■ Fourier method
  - SITCOM (F. di Giuseppe; 2D structure)
  - Ice clouds (R. Hogan, S. Kew; 2.5D structure)



# Conclusions

- Developed/extended an algorithm
  - Full 3D structure
  - LWC height profile
  - Local measured constraints (fine or coarse)
  - Cloud mask
- Advantages
  - Flexible
  - Dimensions
  - Instruments
  - Vary the statistics easily and independently



# More information

- Homepage
  - Papers, Matlab-programs, examples
- <http://www.meteo.uni-bonn.de/venema/themes/surrogates/>
- Google: surrogate clouds
- BBC campaign surrogates
  - <ftp://bbc.knmi.nl/bbc1/model/>
- [Victor.Venema@uni-bonn.de](mailto:Victor.Venema@uni-bonn.de)



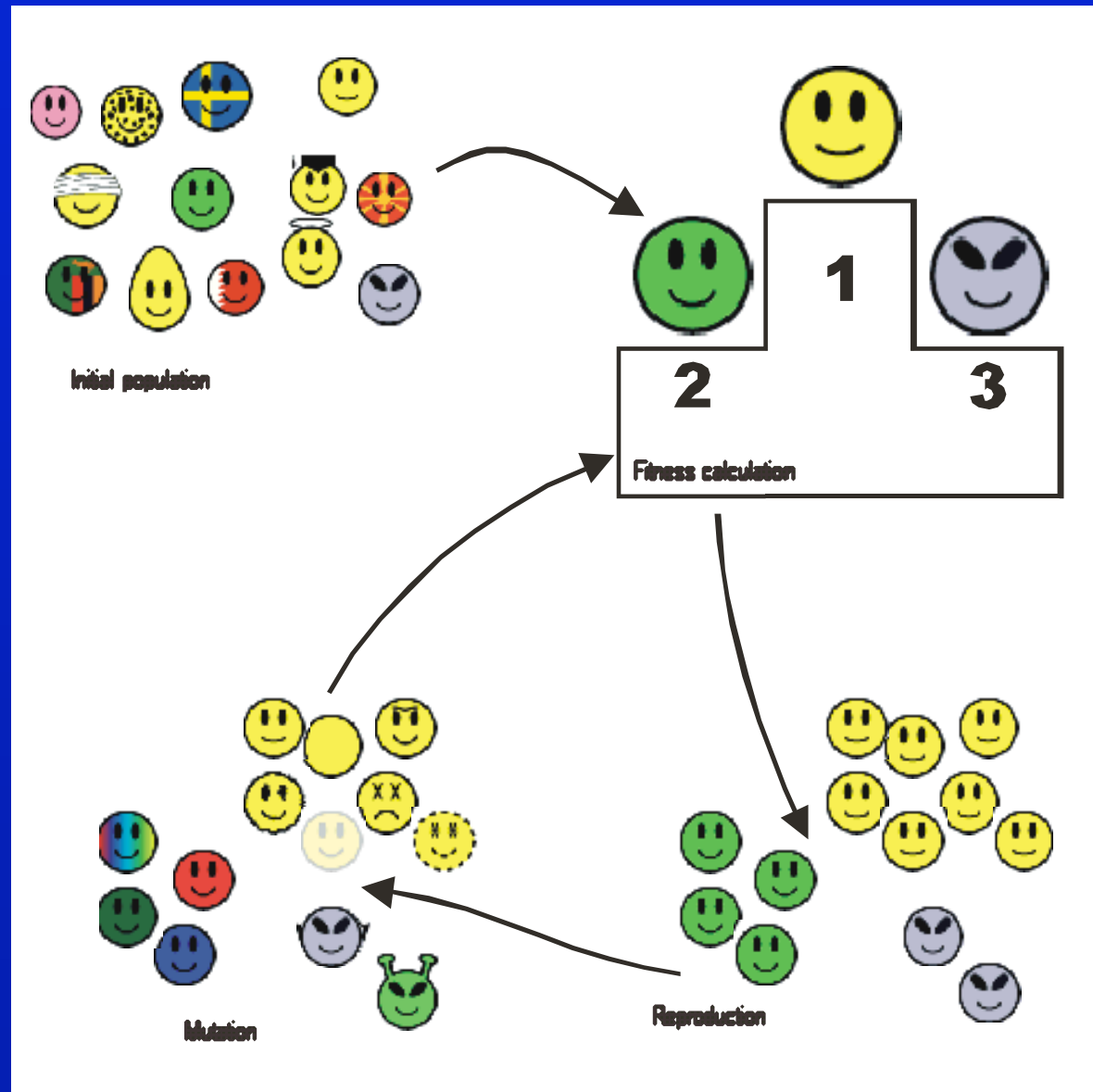
# Constrained surrogates

- Arbitrary constraints
- Evolutionary search algorithm
- Better convergence
- Try new statistics
- Fractal geometry for cloud boundaries





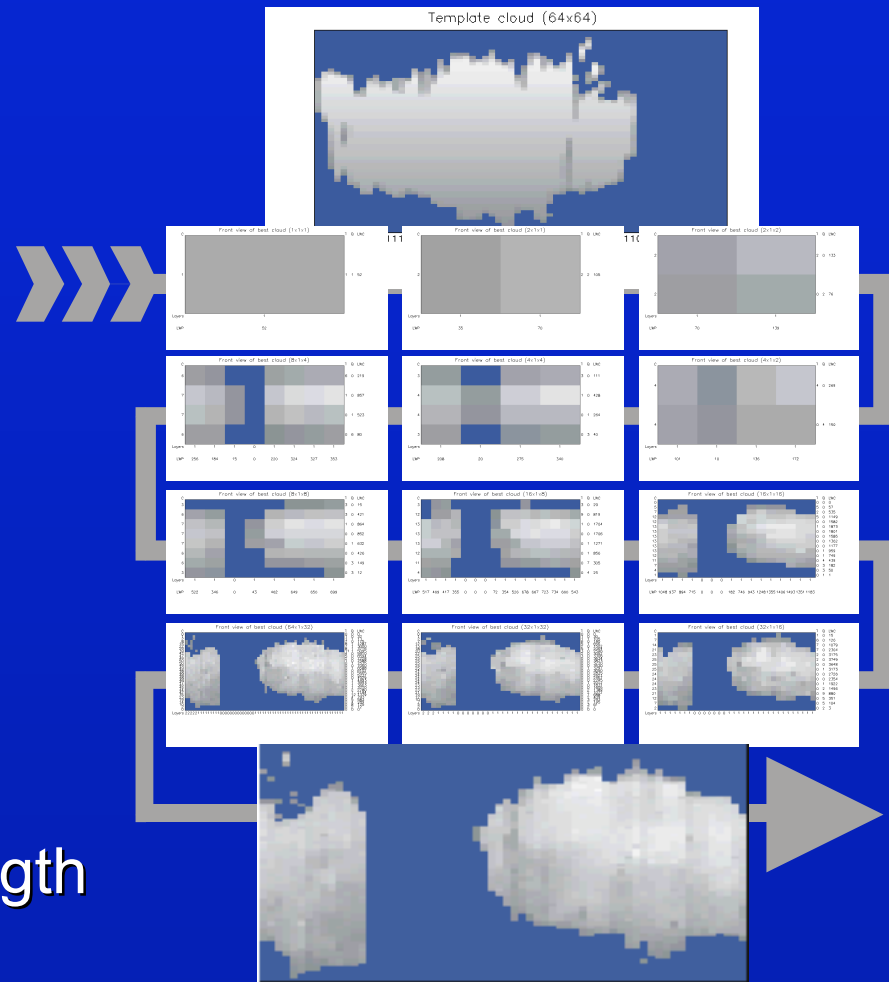
# Evolutionary search algorithm





# Constrained surrogates

- height profiles
  - cloud base
  - cloud top
  - cloud cover
  - average LWC
- Histograms
  - LWP
  - LWC
  - number of layers
- Power spectra & length
  - LWP
  - Highest cloud top
  - Lowest cloud base





# Coarse mean surrogates

- Input
  - Local coarse mean LWP,  $\tau$
  - Local coarse mean cloud fraction
  - Power spectrum, extrapolated to small scales
- Combine satellite and ground based or in situ measurements
  - Measured small scale spectrum or PDF
- Downscaling models
  - A priori small scale spectrum



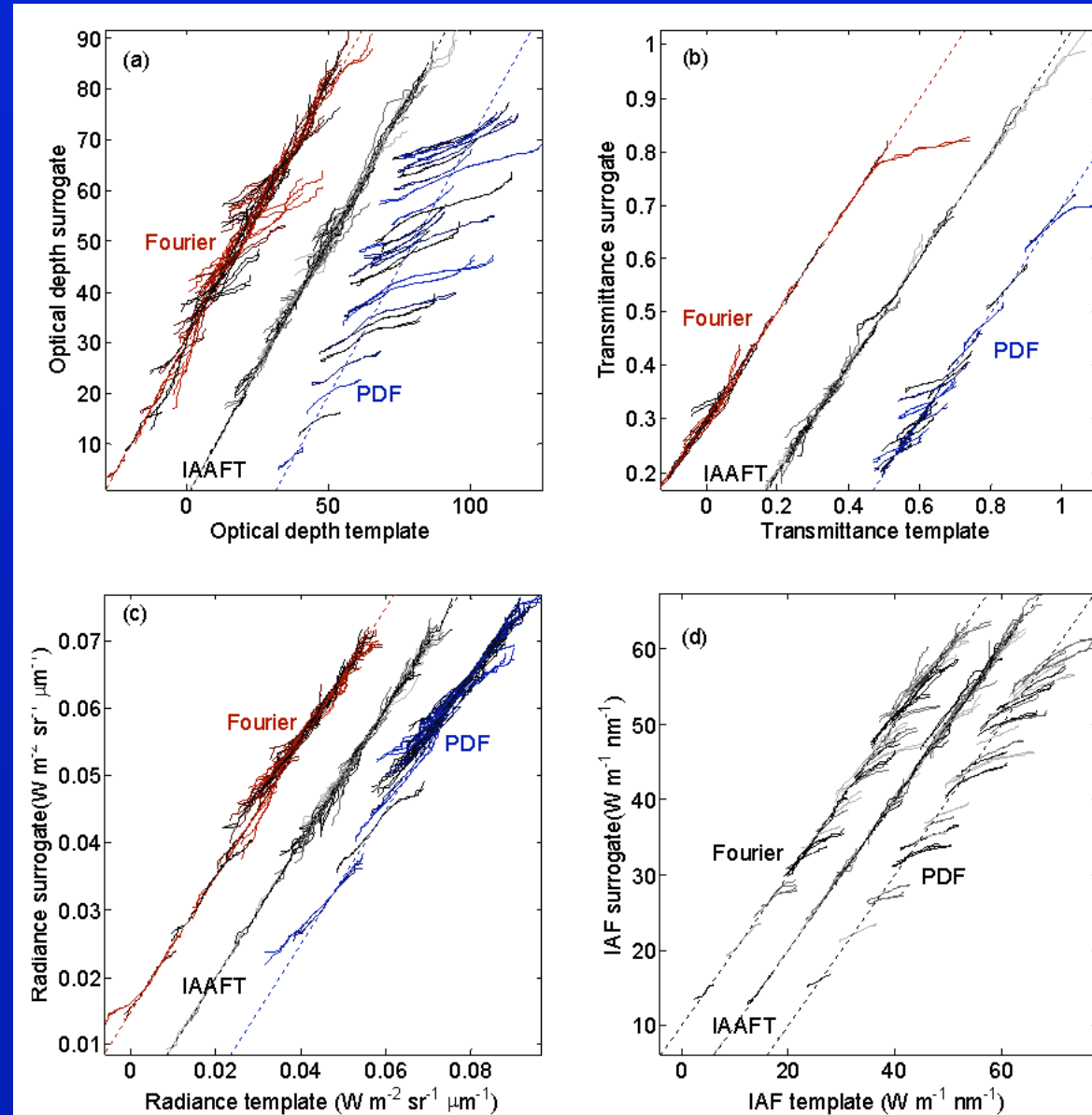
# Instruments

- 3 microwave radiometers,
- 3 cloud radars,
- 4 Micro Rain Radars (MRRs),
- 2 wind profiler-RASS systems, to measure wind and temperature profiles,
- 4 lidar ceilometers,
- 2 lidars
- numerous radiation, precipitation, turbulence and meteorological instruments.



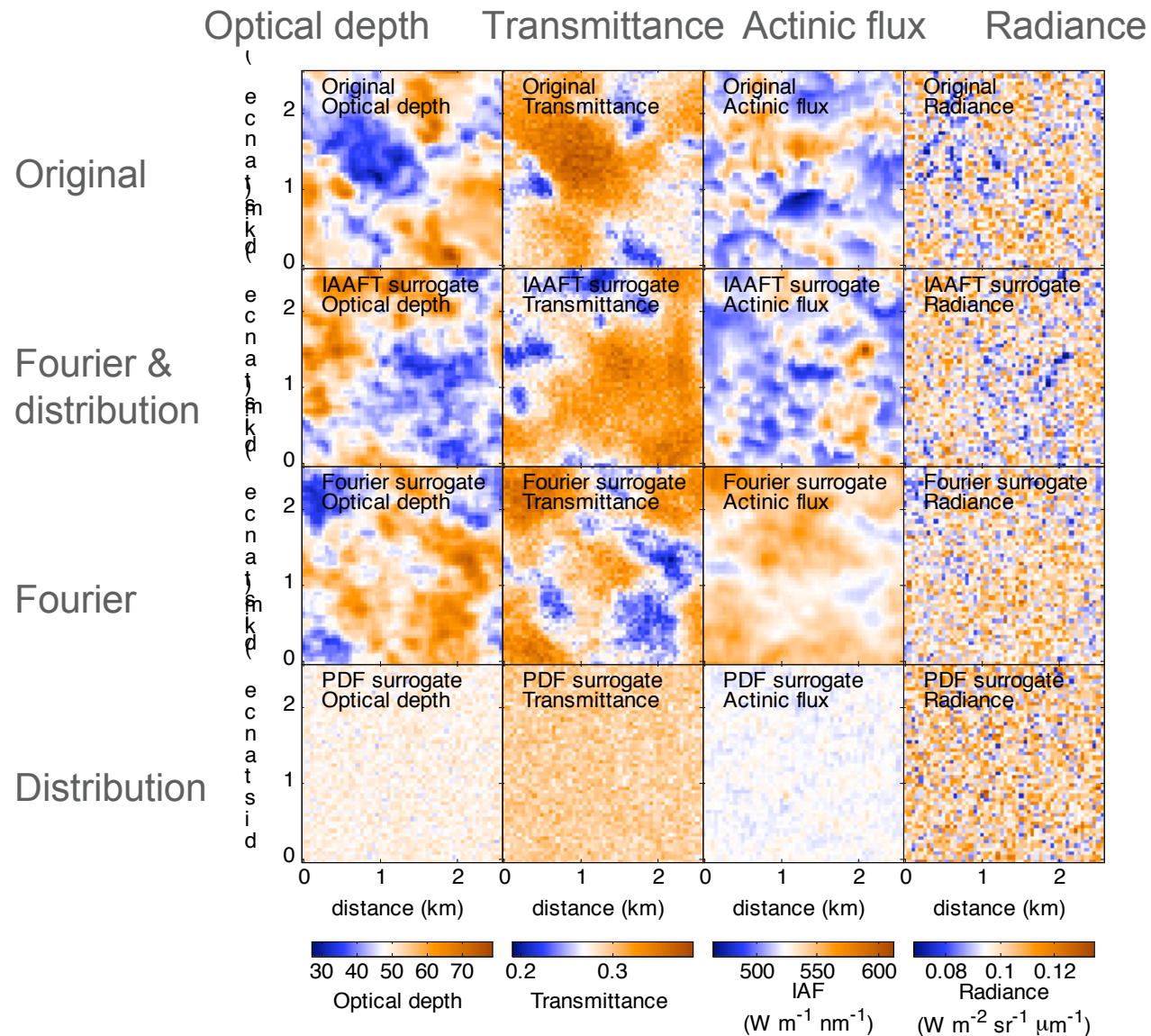


# LES Surrogates - Radiation





# LES Surrogates - Radiation





# LES Surrogates - Radiation

